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Radioactive Characterization Analysis about Metal Cask of Spent Nuclear Fuel after Design Life Expiration

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Abstract

The Korea Radioactive Waste Agency (KORAD) has developed a dual-purpose metal cask for the dry storage of spent nuclear fuel that has been generated by domestic light-water reactors. The metal cask has been designed in compliance with international and domestic technology standards, and safety was the most important consideration in developing its design. It has been designed to maintain its integrity for 50 years in terms of major safety factors. The metal cask ensures the minimization of waste generated by maintenance activities during the storage period as well as the safe management of waste. An activation evaluation of the main body including internal and external components of metal casks whose design lifetime has expired provides quantitative data on their radioactive inventory. The radioactive inventory of the main body and the components of the metal cask was calculated by applying the MCNP5·ORIGEN-2 evaluation system and by considering each component's chemical composition, neutron flux distribution, and reaction rate, as well as the duration of neutron irradiation during the storage period. From the evaluation results, it was found that 10 years after the end of the cask's design life, ^{60}Co had greater radioactivity than other nuclides among the metal materials. In the case of the neutron shield, nuclides that emit high-energy gamma rays such as ^{28}Al and ^{24}Na immediately after the design lifetime had greater radioactivity. However, their radioactivity level became ignorable after 6 months due to their short half-life. Based on the evaluations of this study it is believed that the nuclide inventory of a spent nuclear fuel metal cask can be utilized as basic data when the decommissioning of a metal cask is planned, for example, for the development of a decommissioning plan, the determination of a decommissioning method, the estimation of radiation exposure of workers engaged in decommissioning operations, the management of radioactive wastes, etc.

1. Introduction

The Korea Radioactive Waste Agency (KORAD) has developed a dual-purpose metal cask (hereinafter, "metal cask") for the dry storage of spent nuclear fuel that has been generated by domestic light-water reactors. The metal cask has been designed in compliance with international and domestic technology standards, and safety was the most important consideration in developing its design [1]. The metal cask has been designed to maintain its integrity for 50 years in terms of major safety factors (e.g., structure, heat removal, confinement, prevention of criticality, radiation shielding, etc.). Furthermore, the cask ensures the minimization of waste generated by maintenance

activities during the storage period as well as the safe management of wastes. A metal storage cask for spent nuclear fuel has the following design features, including aspects related to decommissioning and decontamination:

○ Easy recovery of spent nuclear fuel after the design life;
○ Simple operations for the separation and removal of structures activated after the recovery of spent nuclear fuel;
○ Easy decontamination of the external surface of the canister and the main body;
○ Minimization of the generation of secondary radioactive wastes.

When the metal cask is used to store spent nuclear fuel for 50 years, which is its design life, the main body and components of the cask become activated due to irradiation with neutrons emitted from the spent nuclear fuel. When the design lifetime of the metal cask has ended, data from the radionuclide inventory of its canister, main body, and components provide very important information for decommissioning. The activity levels of radionuclides are directly related to the selection of the decommissioning method [2]. An activation evaluation of the main body and internal/external components of metal casks whose design lifetime has ended provides quantitative data on their radioactive inventory. This study can be utilized as basic data necessary for the decommissioning of the metal cask (i.e., estimation of exposure doses to workers during decommissioning operations, determination of a decontamination technology, assessment of residual radioactivity at facilities/sites, etc.) [3].

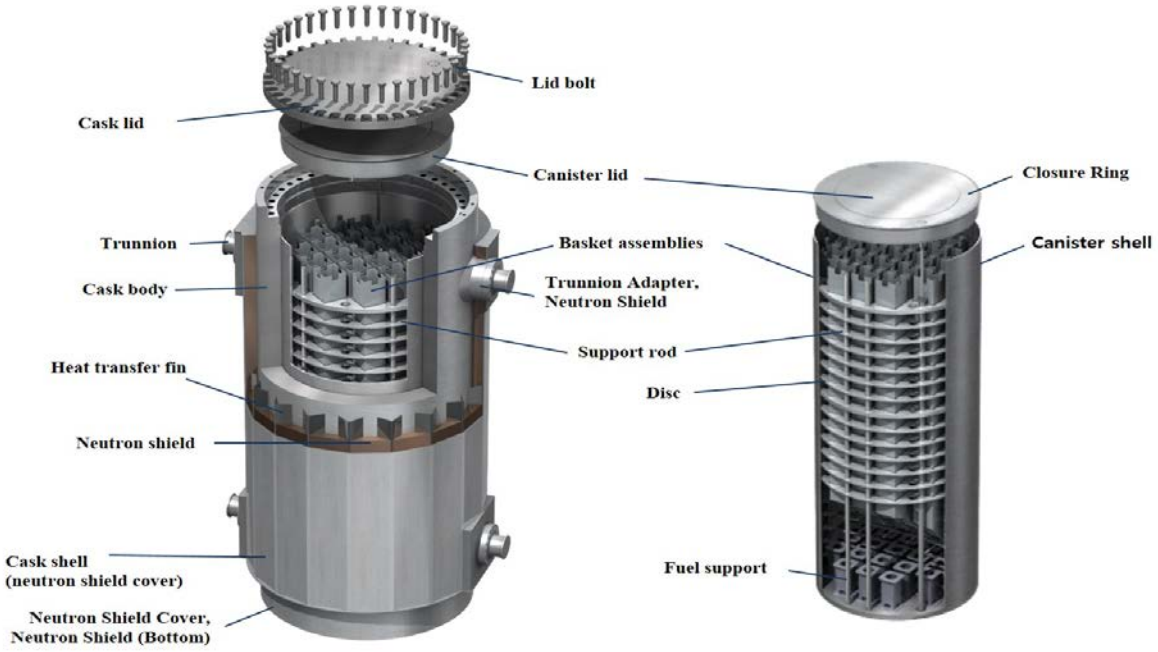
2. Main Discussion

2.1 Cask specifications and description

The metal cask is an independent cylinder and is vertically stored on a concrete or metallic pad. The cask consists of the following:

○ The cylindrical body, composed of a forged carbon steel containment vessel, maintains containment by a bolt fastened forged carbon steel cask lid. Fuel is loaded in the basket assembly for the canister and sealed through welding within the containment vessel, and containment integrity regarding radioactive material is maintained within the internal space, which is filled with helium.
○ The canister is composed of the basket assembly, with a capacity of 21 bundles, a disc that supports the basket assembly, support rod, canister shell, canister baseplate, canister lid, and closure ring. The canister lid and closure ring are sealed by welding after loading with spent nuclear fuel.
○ Neutron shielding resin is filled between the cask body and neutron shield cover, and is located on the cask body side and bottom surfaces.
○ The basket assembly that supports the spent nuclear fuel transfers heat to the cask body. A neutron absorber is installed on the four external sides of the basket cell for absorbing neutrons, to satisfy the nuclear criticality safety requirements.
○ One trunnion pair is installed on the upper portion of the cask to allow convenient lifting of the cask in an upright position. The lower trunnion acts as the contact point for rotating and fastening the metal storage cask under transport conditions.

Table 1 shows the major features of a metal cask that are subject to evaluation in this study (Figure. 1)



(a) Cask (b) Canister

Figure 1. Arrangement of the dual-purpose metal cask

Table 1. A characteristics of metal cask

Component	Dimension
Cask Body(mm)	ø2,404 × 5,285
Cask Lid(mm)	150THK. × ø1,956
Basket Assembly(mm)	241 × 241 × 4,550
Spent Nuclear Fuel	-
- Burnup [MWD/MTU]	45,000
- Enrichment [wt%]	4.5
- Cooling Time [yr]	10
- Loading Fuel Type	21 WH & CE type
Disc(mm)	20(50)THK. × ø1,630
Support Rod(mm)	ø50 × 4,565
Fuel Support(mm)	216 × 216 × 425
Canister(mm)	ø1,686 × 4,880
Design Lifetime [yr]	50

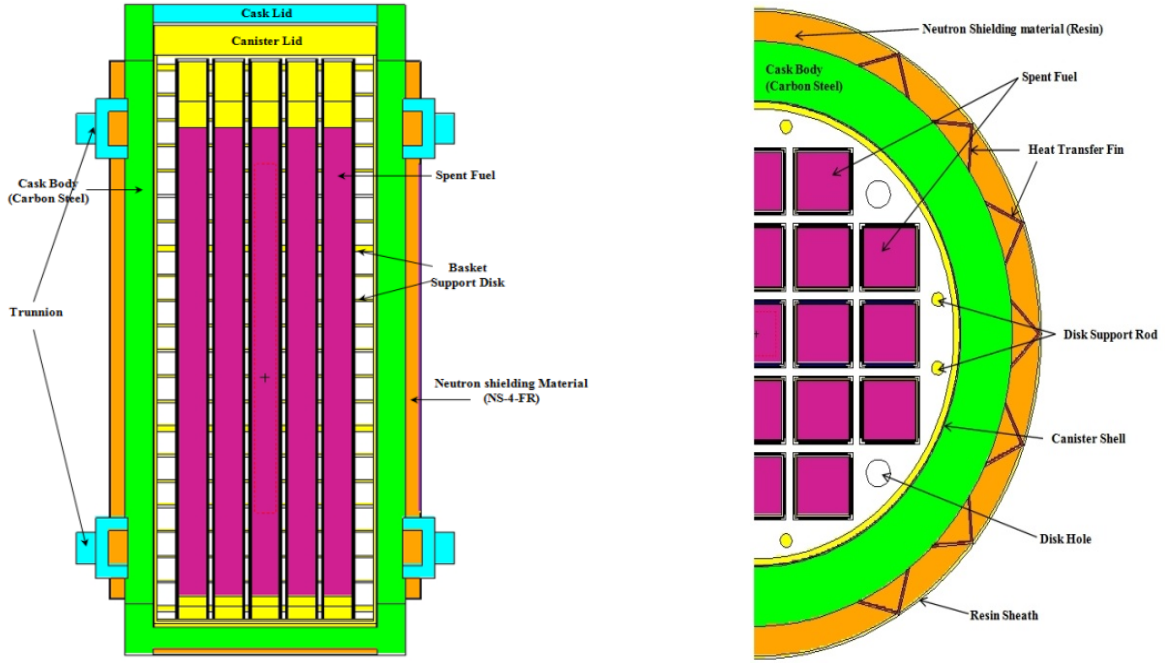
2.2 Computation code and methodology

The metal cask is mostly made of stainless steel and carbon steel except for its neutron shield. Table 2 shows the chemical composition of materials constituting a metal cask [4]. And Table 3 lists radionuclides most frequently generated by neutron irradiation.

The metal cask complies with the stringent ‘Nuclear Quality Assurance Requirements (KEPIC or ASME)’. All materials, except for special materials, will be manufactured and purchased in accordance with the Code (Reference 4). The material of the cask body should suppress the inclusion of impurities that may be present in the metal (S, P, etc.) in accordance with the Code (ASME Boiler and Pressure Vessel Code Section II Part A, SA-350/SA-350M, ‘Chapter 5. Manufacture’). In addition, an analysis is performed in accordance with the code (‘Chapter 6. Chemical Composition’) to determine the chemical composition of the materials specified in "Table 1. Chemical Requirements’ and issued to CMTR (Certified Material Test Report). Accordingly, it is considered that the amount of impurities contained in the cask body is very small.

The neutron shield is a type of resin consisting of organic chemicals, and its chemical composition includes Al, C, O, and H. Estimating the radioactive inventory of the main body and components of a metal cask resulting from neutron irradiation can be conducted using computation codes. This study applies the MCNP5 computation code, which enables a realistic radiation transport analysis of three-dimensional geometrical structures [5]. It was used for calculating the neutron flux and reaction rate of the main body and components of a metal cask, as well as for detailed modeling.

The total neutron flux emitted by the 21 bundles of design basis fuel at the initial stage of loading was evaluated using the ORIGEN-S module of the SCALE 6.1 computation code [6]. From among fuels generated from domestic light-water reactors, the selection of the design basis fuel was made based on the following conditions: the degree of burnup of 45,000MWD/MTU or less; ^{235}U enrichment degree of 4.5wt% or less; and a cooling period of at least 10 years. The total neutron flux emitted from one bundle of design basis fuel is 2.0967E+08 neutrons/cm^{2}sec, and this was used as input data for a geometrical model developed using the MCNP5 computation code, for components of the metal cask (Figure. 2)



(a) Vertical section view of the metal cask (b) Horizontal section view of the metal cask

Figure 2. Vertical and horizontal section of the dual-purpose metal cask

Table 2. Weight fraction for chemical composition of metal cask

Composition	Basket, Support disk	Canister shell, Canister lid	Cask body	Cask lid
	SA-240 304	SA-240 316L	SA-350 LF.3	SA-182 GR.F6NM
C	0.00080	0.00030	0.002	0.0008
N	0.00100	0.00100	-	-
Si	0.00750	0.00750	0.00275	0.0060
P	0.00045	0.00045	0.00035	0.0003
S	0.00030	0.00030	0.0004	0.0003
Cr	0.19000	0.17000	0.0030	0.1275
Mn	0.02000	0.02000	0.0090	0.0075
Fe	0.68745	0.65545	0.9418	0.8054
Ni	0.09250	0.12000	0.0350	0.0450
Mo	-	0.02500	0.0012	0.0075
Cu	-	-	0.0040	-
Nb	-	-	0.0002	-
V	-	-	0.0003	-

Table 3. Reaction formula for radionuclides in activated components

Activated radionuclides	Half life	Reaction formula
^{51}Cr	27.70 day	^{50}Cr(n,γ) ^{51}Cr
^{54}Mn	0.8556 yr	^{54}Fe(n,p) ^{54}Mn
^{55}Fe	2.73 yr	^{54}Fe(n,γ) ^{55}Fe
^{59}Fe	44.50 day	^{58}Fe(n,γ) ^{59}Fe
^{58}Co	70.86 day	^{58}Ni(n,p) ^{58}Co
^{60}Co	5.27 yr	^{69}Co(n,γ) ^{60}Co
^{14}C	5,730 yr	^{14}N(n,p) ^{14}C, ^{13}C(n,γ) ^{14}C
^{16}N	7.13 sec	^{15}N(n,γ) ^{16}N
^{3}H	12.33 yr	^{2}H(n,p) ^{3}H
^{24}Na	14.96 hr.	^{23}Na(n,γ) ^{24}Na
^{28}Al	2.2414 min.	^{27}Al(n,γ) ^{28}Al
^{59}Ni	76,000 yr	^{58}Ni(n,γ) ^{59}Ni
^{63}Ni	100.1 yr	^{62}Ni(n,γ) ^{63}Ni

The neutron cross-section was then obtained by calculating the reaction rate of a parent nuclide activated by neutron flux and irradiation in the main body and each component of a metal cask, using input data such as chemical composition based on the material quality of the components of the metal cask, etc. Based on this method, the neutron cross-section of an activated parent nuclide was corrected in the light-water fuel library of the ORIGEN-2 computation code, and the radioactivity of the radionuclide was calculated again based on neutrons accumulated over the design lifetime [7]. The MCNP code includes libraries of (n,γ), (n,p), (n,d), (n,α), (n,^{3}He), etc. The calculation was done using the (n,γ) reaction cross-section, which represents the largest portion of the code. Figure 3 shows the method and process for estimating the inventory of radionuclides of the components of a metal cask after the end of the cask's design lifetime

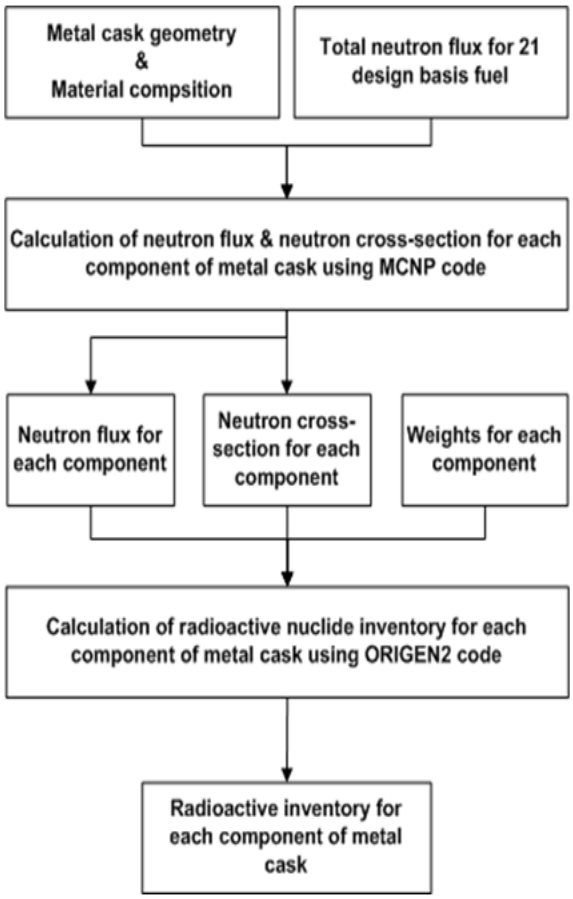


Figure 3. Calculation procedure using MCNP and ORIGEN-2

The following assumptions were applied in estimating the radionuclide inventory of a metal cask.

○ 21 assembles of design basis fuel were stored during the design lifetime of 50 years.
○ All the fuel will be removed when its design lifetime expires.
○ It was assumed that the neutron flux at the beginning of the storage period of spent nuclear fuel was emitted constantly for 50 years.

The design basis fuel has a neutron flux of approximately 4.928E+08 neutrons/cm^{2}·sec immediately after discharge from the nuclear reactor, 2.266E+08 neutrons/cm^{2}·sec at 5 years, and 2.0967E+08 neutrons/cm^{2}·sec at 10 years of cooling, respectively. Consequently, as no major change was expected in the amount released according to the cooling-off period, it was hypothesized that a consistent amount would be released over 50 years.

In this study, an evaluation was conducted on the radioactive inventory of the components of a spent nuclear fuel metal cask over 10 years after its design lifetime using MCNP and ORIGEN-2. The results of the calculation of neutron flux in the main body and components of a metal cask, including the basket that is closest to the fuel, and the neutron shield that is farthest from the fuel, were between 2.54E+05 #/cm^2·sec and 9.66E+03 #/cm^2·sec. The range of relative errors was 0.7% to 2%. In addition, we calculated the reduction of the component's neutron flux caused by the cooling of the spent nuclear fuel (Table 4).

Table 4. Neutron flux of main components by cooling time of spent nuclear fuel

[Unit : neutrons/cm^2·sec]

Component		Fuel cooling time after discharged from a reactor		
		Immediately	5 years	10 years
Canister	Basket	6.00E+05	2.75E+05	2.5446E+05
	Disk	1.59E+05	7.33E+04	6.7827E+04
	Bottom plate	1.09E+05	5.03E+04	4.6496E+04
	Shell	2.77E+05	1.27E+05	1.1784E+05
	Lid	3.38E+04	1.57E+04	1.4364E+04
Cask body	Body (upper)	2.27E+00	1.04E+00	9.6588E-01
	Body (middle)	6.15E+01	2.83E+01	2.6176E+01
	Body (lower)	1.39E+01	6.39E+00	5.9165E+00
	Lid	1.77E+00	8.16E-01	7.5209E-01
	Side resin	3.94E+04	1.81E+04	1.6780E+04

2.3 Results of Calculation

The reaction cross-section of major nuclides was calculated based on the neutron flux and reaction rate of each component of the metal cask. The calculation results replaced the corresponding value of the PWR library of the ORIGEN-2 computation code to reflect the operation period of the metal cask. The radioactive inventory was then calculated for each time point of decommissioning. The calculation results of reaction rates by major nuclides were greatly affected by the characteristics of the relevant nuclide, and the relative errors of the calculation were mostly below 2%.

Refer to Tables 5 ~ Table 12 for the radioactivity of major nuclides over time, from immediately after the design lifetime to various time points. The results of the evaluation of radioactive inventory of the main body and each component of a metal cask indicated that ^{54}Mn,^{55}Fe,^{60}Co,^{59}Ni, and ^{63}Ni were the major radionuclides generated by elements of the stainless steel and carbon steel, which were the two major materials forming the metal cask. In particular, the radioactivity of ^{60}Co was found to be relatively larger in all the metal cask components, due to the electron capture and decay of Ni and Fe, the major metal elements of the steels, after neutron irradiation. From the neutron shield, light elements such as ^{3}H, ^{10}Be, ^{14}C, ^{28}Al, and ^{24}Na were mostly generated. Immediately after the design life, nuclides such as ^{28}Al and ^{24}Na had relatively greater radioactivity. However, since the half-life of the radioactivity of these nuclides (^{28}Al: 2.24min. and ^{24}Na: 14.96hr.) is very short, the level of their radioactivity is significantly reduced with a delay of decommissioning. After about 6 months, their radioactivity reaches an ignorable level.

Table 5. Specific activities of canister basket after design lifetime expiration.

[Unit : Bq/g]

Nuclide	Duration after design lifetime expiration					
	Immediately	0.05yr	0.1yr	0.5yr	1.0yr	5.0yr
^{51}Cr	3.46E-05	2.19E-05	1.39E-05	3.58E-07	3.72E-09	4.99E-25
^{54}Mn	3.29E-07	3.16E-07	3.04E-07	2.19E-07	1.46E-07	5.73E-09
^{55}Fe	3.67E-06	3.62E-06	3.58E-06	3.22E-06	2.81E-06	9.69E-07
^{59}Fe	2.39E-07	1.80E-07	1.36E-07	1.43E-08	8.61E-10	1.45E-19
^{58}Co	1.22E-05	1.02E-05	8.51E-06	2.04E-06	3.40E-07	2.08E-13
^{60}Co	7.16E-03	7.11E-03	7.06E-03	6.70E-03	6.27E-03	3.71E-03
^{59}Ni	8.83E-08	8.83E-08	8.83E-08	8.83E-08	8.83E-08	8.83E-08
^{63}Ni	1.05E-05	1.05E-05	1.04E-05	1.04E-05	1.04E-05	1.01E-05

Table 6. Specific activities of canister disk after design lifetime expiration.

[Unit : Bq/g]

Nuclide	Duration after design lifetime expiration					
	Immediately	0.05yr	0.1yr	0.5yr	1.0yr	5.0yr
^{51}Cr	2.48E-07	1.57E-07	9.97E-08	2.58E-09	2.67E-11	3.58E-27
^{54}Mn	1.85E-09	1.78E-09	1.71E-09	1.23E-09	8.23E-10	3.22E-11
^{55}Fe	2.11E-08	2.09E-08	2.06E-08	1.85E-08	1.62E-08	5.58E-09
^{59}Fe	4.50E-09	3.40E-09	2.56E-09	2.70E-10	1.62E-11	2.73E-21
^{58}Co	7.59E-08	6.35E-08	5.31E-08	1.27E-08	2.12E-09	1.30E-15
^{60}Co	1.88E-04	1.86E-04	1.85E-04	1.76E-04	1.65E-04	9.72E-05
^{59}Ni	5.51E-10	5.51E-10	5.51E-10	5.51E-10	5.51E-10	5.51E-10
^{63}Ni	6.52E-08	6.52E-08	6.51E-08	6.49E-08	6.47E-08	6.28E-08

Table 7. Specific activities of canister bottom plate after design lifetime expiration.

[Unit : Bq/g]

Nuclide	Duration after design lifetime expiration					
	Immediately	0.05yr	0.1yr	0.5yr	1.0yr	5.0yr
^{10}Be	1.57E-13	1.57E-13	1.57E-13	1.57E-13	1.57E-13	1.57E-13
^{14}C	2.06E-06	2.06E-06	2.06E-06	2.06E-06	2.06E-06	2.06E-06

^{32}P	6.25E-06	2.58E-06	1.06E-06	8.94E-10	1.09E-13	5.63E-28
^{51}Cr	5.70E-03	3.61E-03	2.29E-03	5.92E-05	6.14E-07	8.23E-23
^{54}Mn	4.47E-04	4.29E-04	4.12E-04	2.98E-04	1.99E-04	7.78E-06
^{55}Fe	3.99E-03	3.93E-03	3.88E-03	3.49E-03	3.05E-03	1.05E-03
^{59}Fe	1.05E-04	7.89E-05	5.96E-05	6.28E-06	3.77E-07	6.35E-17
^{58}Co	9.36E-04	7.83E-04	6.54E-04	1.57E-04	2.62E-05	1.60E-11
^{60}Co	8.21E-03	8.16E-03	8.11E-03	7.69E-03	7.20E-03	4.25E-03
^{59}Ni	6.79E-06	6.79E-06	6.79E-06	6.79E-06	6.79E-06	6.79E-06
^{63}Ni	7.63E-04	7.63E-04	7.63E-04	7.60E-04	7.58E-04	7.35E-04

Table 8. Specific activities of canister shell plate after design lifetime expiration.

[Unit : Bq/g]

Nuclide	Duration after design lifetime expiration					
	Immediately	0.05yr	0.1yr	0.5yr	1.0yr	5.0yr
^{10}Be	3.00E-13	3.00E-13	3.00E-13	3.00E-13	3.00E-13	3.00E-13
^{14}C	4.77E-06	4.77E-06	4.77E-06	4.77E-06	4.77E-06	4.77E-06
^{32}P	1.45E-05	5.97E-06	2.46E-06	2.07E-09	2.92E-13	2.97E-27
^{51}Cr	1.32E-02	8.35E-03	5.29E-03	1.37E-04	1.42E-06	1.90E-22
^{54}Mn	1.03E-03	9.93E-04	9.54E-04	6.89E-04	4.60E-04	1.80E-05
^{55}Fe	9.22E-03	9.10E-03	8.98E-03	8.07E-03	7.07E-03	2.43E-03
^{59}Fe	2.42E-04	1.82E-04	1.38E-04	1.45E-05	8.70E-07	1.47E-16
^{58}Co	2.15E-03	1.80E-03	1.50E-03	3.59E-04	6.01E-05	3.67E-11
^{60}Co	7.69E-04	7.64E-04	7.59E-04	7.20E-04	6.74E-04	3.98E-04
^{59}Ni	1.56E-05	1.56E-05	1.56E-05	1.56E-05	1.56E-05	1.56E-05
^{63}Ni	1.75E-03	1.75E-03	1.75E-03	1.75E-03	1.74E-03	1.69E-03

Table 9. Specific activities of canister lid plate after design lifetime expiration.

[Unit : Bq/g]

Nuclide	Duration after design lifetime expiration					
	Immediately	0.05yr	0.1yr	0.5yr	1.0yr	5.0yr
^{10}Be	3.78E-14	3.78E-14	3.78E-14	3.78E-14	3.78E-14	3.78E-14
^{14}C	5.82E-07	5.82E-07	5.82E-07	5.81E-07	5.81E-07	5.81E-07
^{32}P	1.76E-06	7.27E-07	3.00E-07	2.52E-10	3.73E-14	4.41E-29
^{51}Cr	1.61E-03	1.02E-03	6.45E-04	1.67E-05	1.73E-07	2.32E-23

^{54}Mn	1.26E-04	1.21E-04	1.16E-04	8.40E-05	5.61E-05	2.19E-06
^{55}Fe	1.12E-03	1.11E-03	1.09E-03	9.84E-04	8.61E-04	2.97E-04
^{59}Fe	2.94E-05	2.22E-05	1.68E-05	1.77E-06	1.06E-07	1.79E-17
^{58}Co	2.62E-04	2.19E-04	1.83E-04	4.38E-05	7.33E-06	4.48E-12
^{60}Co	3.56E-04	3.54E-04	3.51E-04	3.33E-04	3.12E-04	1.84E-04
^{59}Ni	1.90E-06	1.90E-06	1.90E-06	1.90E-06	1.90E-06	1.90E-06
^{63}Ni	2.14E-04	2.14E-04	2.14E-04	2.13E-04	2.12E-04	2.06E-04

Table 10. Specific activities of cask body plate after design lifetime expiration.

[Unit : Bq/g]

Nuclide	Duration after design lifetime expiration					
	Immediately	**0.05yr**	**0.1yr**	**0.5yr**	**1.0yr**	**5.0yr**
^{51}Cr	2.54E-11	1.61E-11	1.02E-11	2.66E-13	1.09E-15	1.46E-31
^{54}Mn	2.17E-13	2.09E-13	2.00E-13	1.45E-13	9.60E-14	3.95E-15
^{55}Fe	2.61E-12	2.57E-12	2.54E-12	2.28E-12	2.00E-12	6.88E-13
^{59}Fe	3.90E-13	2.96E-13	2.22E-13	2.31E-14	4.06E-15	6.85E-25
^{58}Co	1.09E-11	9.09E-12	7.60E-12	1.82E-12	3.04E-13	1.85E-19
^{60}Co	1.56E-08	1.55E-08	1.54E-08	1.46E-08	1.37E-08	8.07E-09
^{59}Ni	7.88E-14	7.88E-14	7.88E-14	7.88E-14	7.88E-14	7.88E-14
^{63}Ni	9.33E-12	9.32E-12	9.32E-12	9.29E-12	9.26E-12	8.98E-12

Table 11. Specific activities of cask lid plate after design lifetime expiration.

[Unit : Bq/g]

Nuclide	Duration after design lifetime expiration					
	Immediately	**0.05yr**	**0.1yr**	**0.5yr**	**1.0yr**	**5.0yr**
^{51}Cr	5.05E-12	3.20E-12	2.02E-12	5.49E-14	0.00E+00	0.00E+00

^{54}Mn	4.40E-14	4.22E-14	4.05E-14	2.85E-14	1.84E-14	8.82E-16
^{55}Fe	5.25E-13	5.18E-13	5.11E-13	4.59E-13	4.02E-13	1.39E-13
^{59}Fe	1.20E-13	9.11E-14	6.55E-14	5.97E-15	0.00E+00	0.00E+00
^{58}Co	2.15E-12	1.80E-12	1.51E-12	3.63E-13	6.02E-14	3.68E-20
^{60}Co	5.08E-09	5.04E-09	5.01E-09	4.75E-09	4.45E-09	2.63E-09
^{59}Ni	1.56E-14	1.56E-14	1.56E-14	1.56E-14	1.56E-14	1.56E-14
^{63}Ni	1.85E-12	1.85E-12	1.85E-12	1.84E-12	1.83E-12	1.78E-12

Table 12. Specific activities of cask resin plate after design lifetime expiration.

[Unit : Bq/g]

Nuclide	**Duration after design lifetime expiration**					
	Immediately	**0.05yr**	**0.1yr**	**0.5yr**	**1.0yr**	**5.0yr**
^{3}H	2.97E-15	2.97E-15	2.97E-15	2.91E-15	2.84E-15	2.24E-15
^{10}Be	2.24E-17	2.24E-17	2.24E-17	2.24E-17	2.24E-17	2.24E-17
^{14}C	1.83E-12	1.83E-12	1.83E-12	1.83E-12	1.83E-12	1.83E-12
^{24}Na	1.76E-09	2.82E-18	4.51E-27	0.00E+00	0.00E+00	0.00E+00
^{28}Al	1.72E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

3. Conclusion

The radioactive inventory of a metal cask used for storing spent nuclear fuel, with a design lifetime of 50 years, was evaluated at the time point immediately after its design lifetime ended, and over the subsequent course of time. The radioactive inventory of the main body and components of the metal cask was calculated by applying the MCNP5·ORIGEN-2 evaluation system and by considering each component's chemical composition, neutron flux distribution, and reaction rate, as well as the duration of neutron irradiation during the storage period.

From the evaluation results, it was found that 5 years after end of the cask's design lifetime, ^{60}Co had greater radioactivity than other nuclides among the metal materials. In the case of the neutron shield, nuclides that emit high-energy gamma rays such as ^{28}Al and ^{24}Na immediately after the design lifetime had greater radioactivity. However, their radioactivity level became ignorable after 6 months due to their short half-life.

Based on the evaluations of this study it is believed that the nuclide inventory of a spent nuclear fuel metal cask can be utilized as basic data when the decommissioning of a metal cask is planned, for example, for the development of a decommissioning plan, the determination of a

decommissioning method, the estimation of radiation exposure of workers engaged in decommissioning operations, the management of radioactive wastes, etc. The surface exposure dose rates of the canister and the main body of the metal cask from which the spent nuclear fuel had been removed with expiration of the design lifetime of 50 years were evaluated to be at very low levels, and the radiation exposure doses to which radiation workers are subjected during the decommissioning process appeared to be at negligible levels.

In addition, it will be possible to use this evaluation method to predict the radiation exposure doses of radiation workers during the decommissioning of other component parts of the metal cask, and the obtained results later can be used as basic data for decommissioning storage casks. The confinement system of a storage cask is based on a dry process and limits any contamination risks to the inside of the canister. Therefore, the contamination of the metal cask body or its components during its design lifetime is highly unlikely. A very small amount of contaminants may be accumulated inside a canister due to the possibility of the canister inside coming into contact with a fuel assembly that has been contaminated inside a storage pool, but the degree of contamination is expected to be insignificant.

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